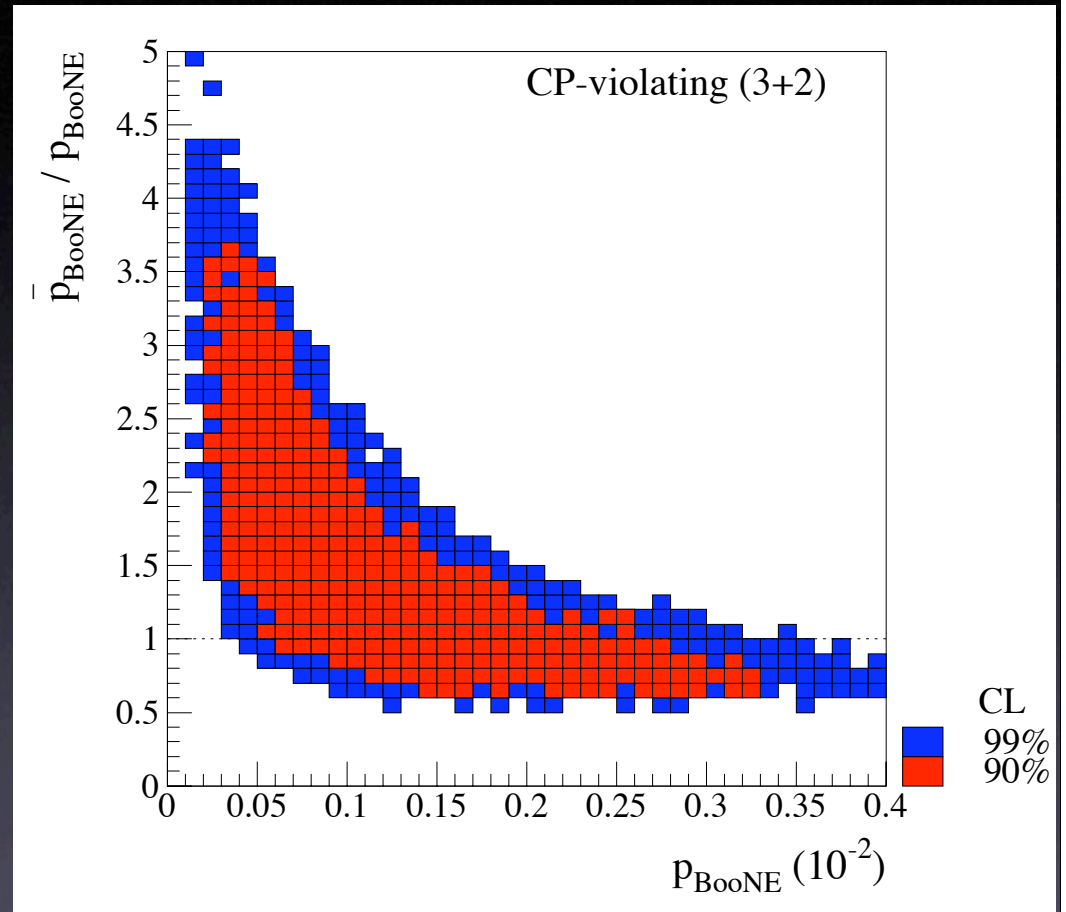


Antineutrino Running at MiniBooNE

Morgan Wascko, LSU

Motivation

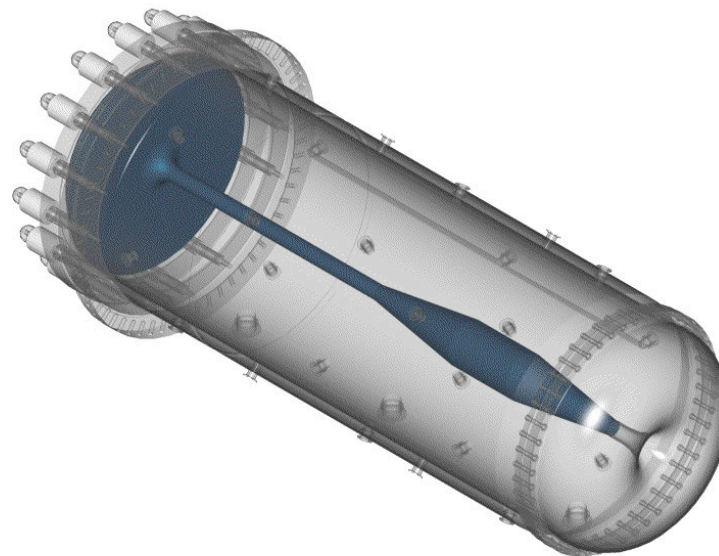
- $\bar{\nu}$ running is a subject of much interest
- CP violation in ν sector
- Difference in oscillation probabilities for $\nu, \bar{\nu}$
- Major experimental obstacles:
 - $\bar{\nu}$ cross sections not well known
 - wrong sign backgrounds
 - ν in a $\bar{\nu}$ beam



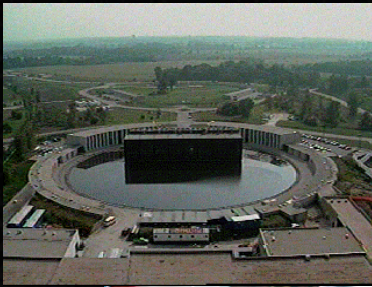
Asymmetry of $\bar{\nu}, \nu$ oscillation probabilities in MiniBooNE versus ν oscillation prob.

Outline

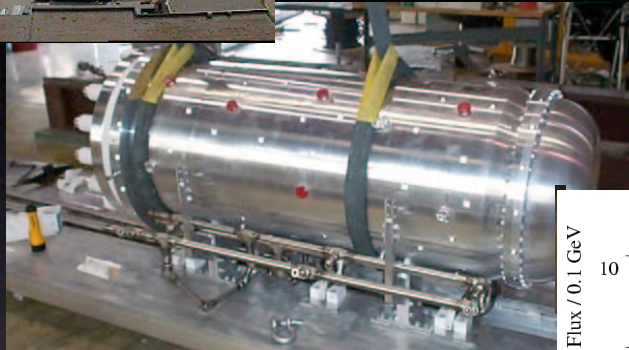
- Focus on WS BGs
- What MiniBooNE can do with one year of antineutrino running
 - $2.0E20$ POT total
 - Cross section physics
 - Oscillations
- <http://www-boone.fnal.gov/publicpages/loi.ps.gz>
- Timescale



Images of the MiniBooNE horn



Extract 8 GeV protons from Fermilab Booster
1.7 λ beryllium target (HARP results soon!)

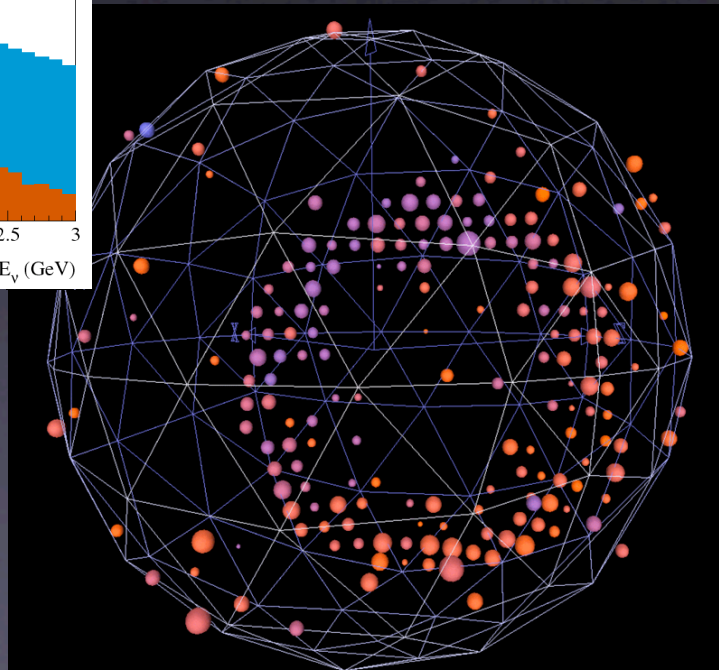
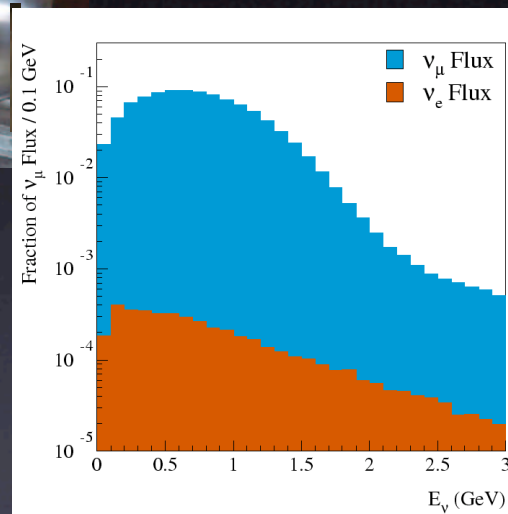


Reversible magnetic horn
Focusses mesons of specific charge
Allows antineutrino running!

50 m decay region
>99% muon neutrinos
both ν and $\bar{\nu}$

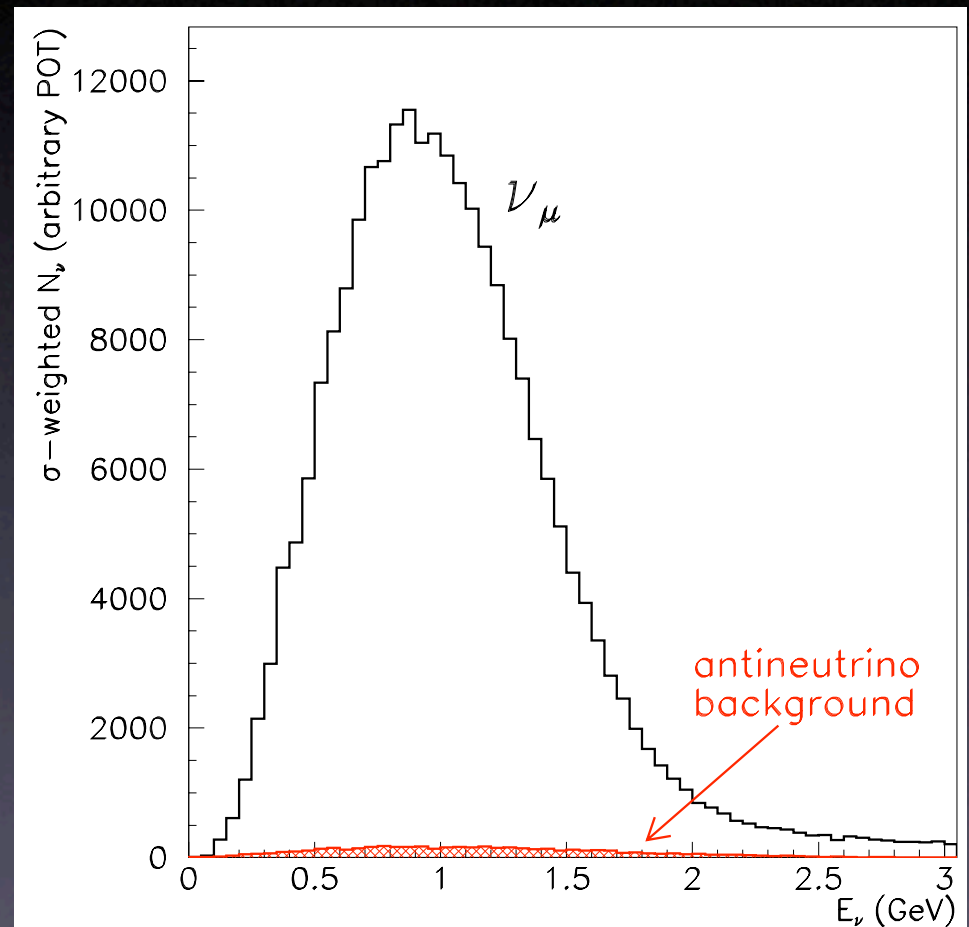
490 m dirt
800 ton CH_2 detector
1520 PMTs

1280 in main tank
240 in veto region



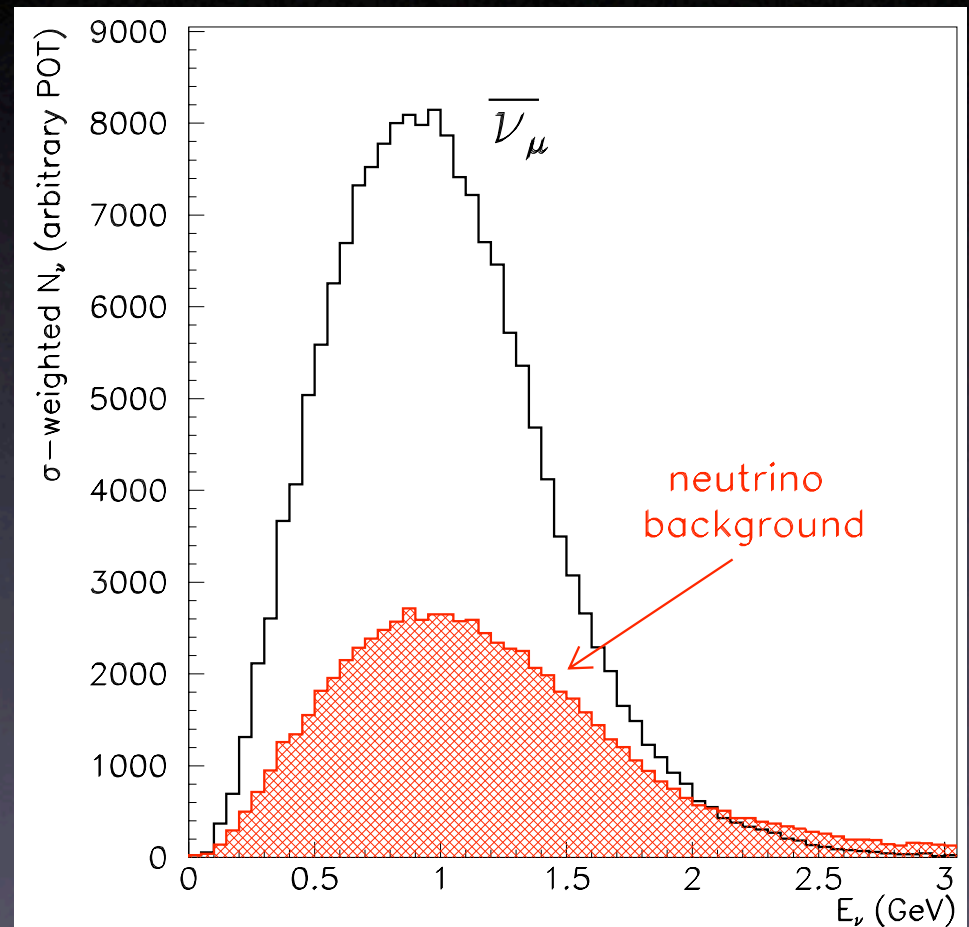
Wrong Sign BGs

- In neutrino running, wrong sign backgrounds are very small (2%)
- In antineutrino running they are much larger (~30%)
- Cherenkov calorimeters cannot distinguish μ^- from μ^+
- Need a way to extract the WS BGs!



Wrong Sign BGs

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- In antineutrino running they are much larger (~30%)
- Cherenkov calorimeters cannot distinguish μ^- from μ^+ (event by event)
- Need a way to extract the WS BGs!

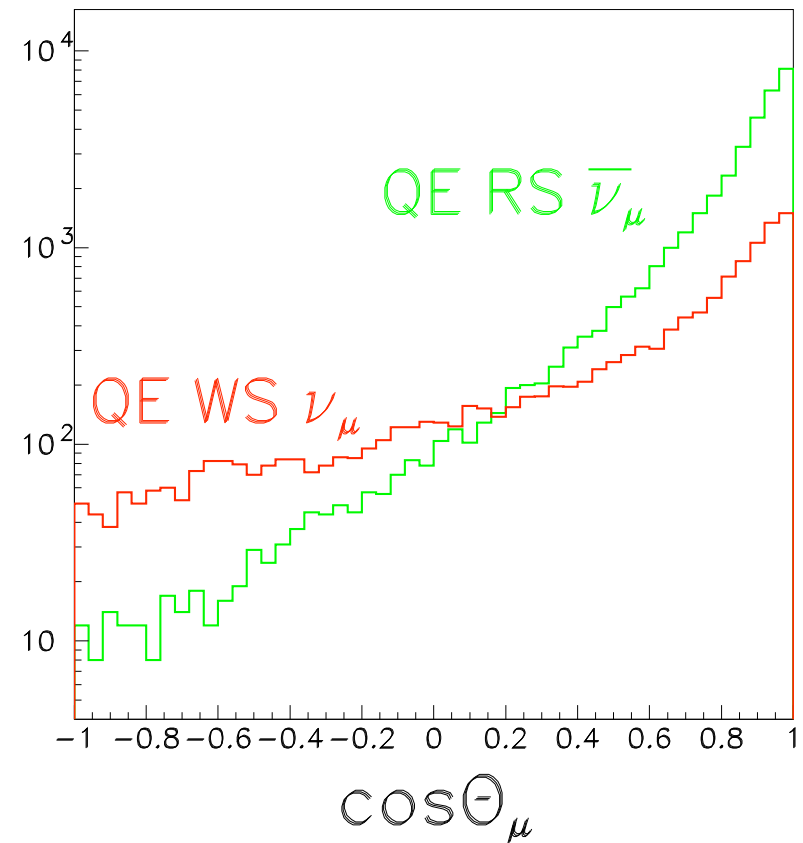


Constraining WS BGs

- MiniBooNE has developed three methods of constraining the overall fraction of $\nu, \bar{\nu}$
 - μ direction
 - μ lifetime
 - $\text{CC}\pi^+$ event selection
- Independent constraints
- Sensitive to total WS fraction
 - Not sensitive to energy spectrum of WS events

WS BG Constraints: μ Direction

- Softer Q^2 spectrum for antineutrino events means more forward-peaked μ
- Can fit angular distribution shape and extract RS/WS fractions
- Using generated muon directions, can extract WS fraction with 5% uncertainty



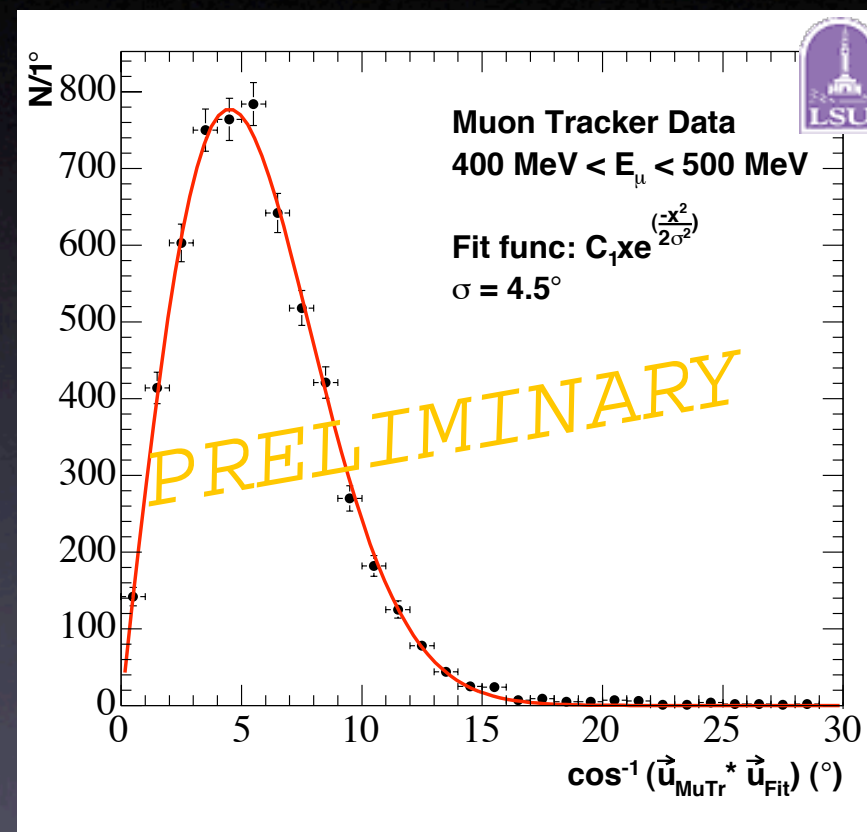
WS BG Constraints: μ Direction

- MiniBooNE has very good angular reconstruction
- Tested with cosmic muon calibration system
- Fit distribution of

$$\cos^{-1}(\vec{u}_{MuTr} \cdot \vec{u}_{Fit})$$

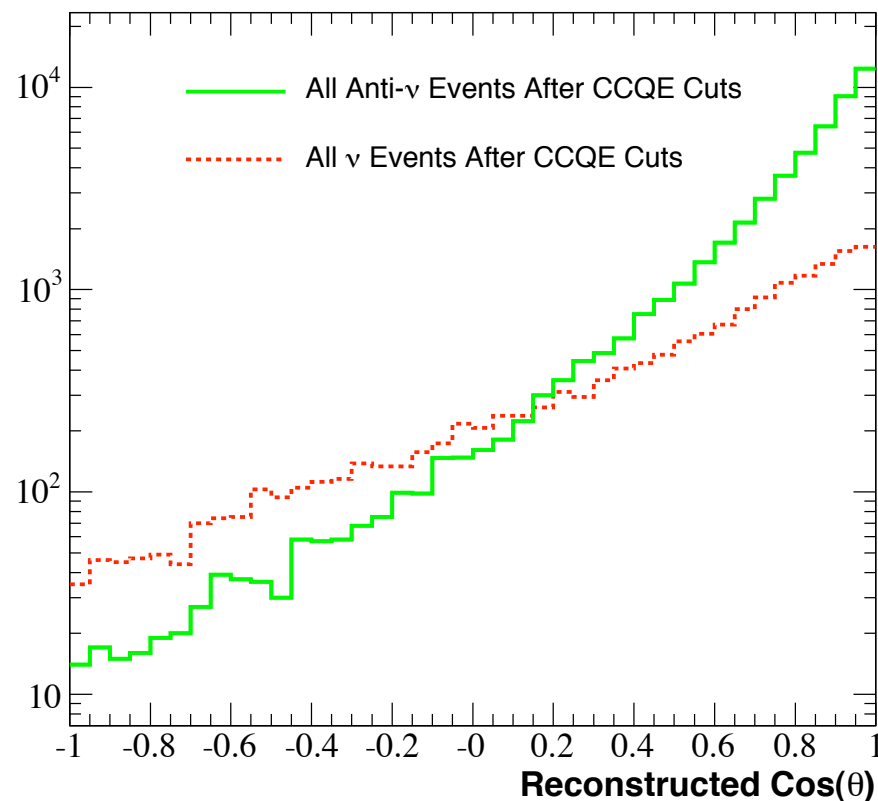
$$xe^{-x^2/2\sigma^2}$$

- (projection of a 2D Gaussian)
- Extract intrinsic resolution of muon tracker
- Angular resolution = 4.0°



WS BG Constraints: μ Directions

- Reconstruction has little effect on this constraint
- WS fraction can be measured to 7% with reconstructed angles
- Can also use Q^2 distributions
 - Similar precision
 - Stronger constraint
 - Poorer resolution
 - Larger uncertainties



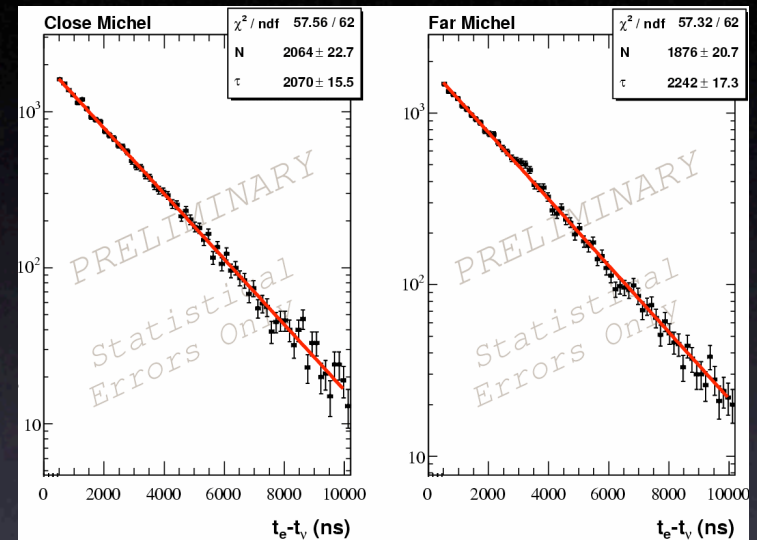
WS BG Constraints: CC π^+ Selection

- Use CC π^+ event selection:
- Tag $\nu_\mu N \rightarrow \mu^- \pi^+ N$ events with two Michel electrons
- π^- captured by carbon, do not decay
 - Cannot tag $\bar{\nu}_\mu N \rightarrow \mu^+ \pi^- N$ events: only 1 Michel
- Two Michel sample is 85% pure WS
- Constrain WS fraction with 15% uncertainty

Neutrino type	# before cuts	# after cuts
ν_μ (WS)	30,539	2,525
$\bar{\nu}_\mu$ (RS)	71,547	461
Total	102,086	2,986

WS BG Constraints: μ Lifetime

- Use muon decay rate in mineral oil to constrain WS BGs
- 8% μ^- capture probability on carbon
 - $\tau_{\mu^-} = 2.026\mu\text{s}$, $\tau_{\mu^+} = 2.197\mu\text{s}$
- Can extract WS contribution with 30% uncertainty
- Independent of kinematics and reconstruction



μ^- lifetime μ^+ lifetime

Comparison of muon lifetimes
from $\text{CCI}\pi^+$ data sample

WS BG Constraints: Summary

Measurement	WS uncertainty	resultant $\bar{\nu}_\mu$ σ error
$\cos\theta_\mu$	7%	2%
$CC \pi^+$	15%	5%
μ Lifetimes	30%	9%

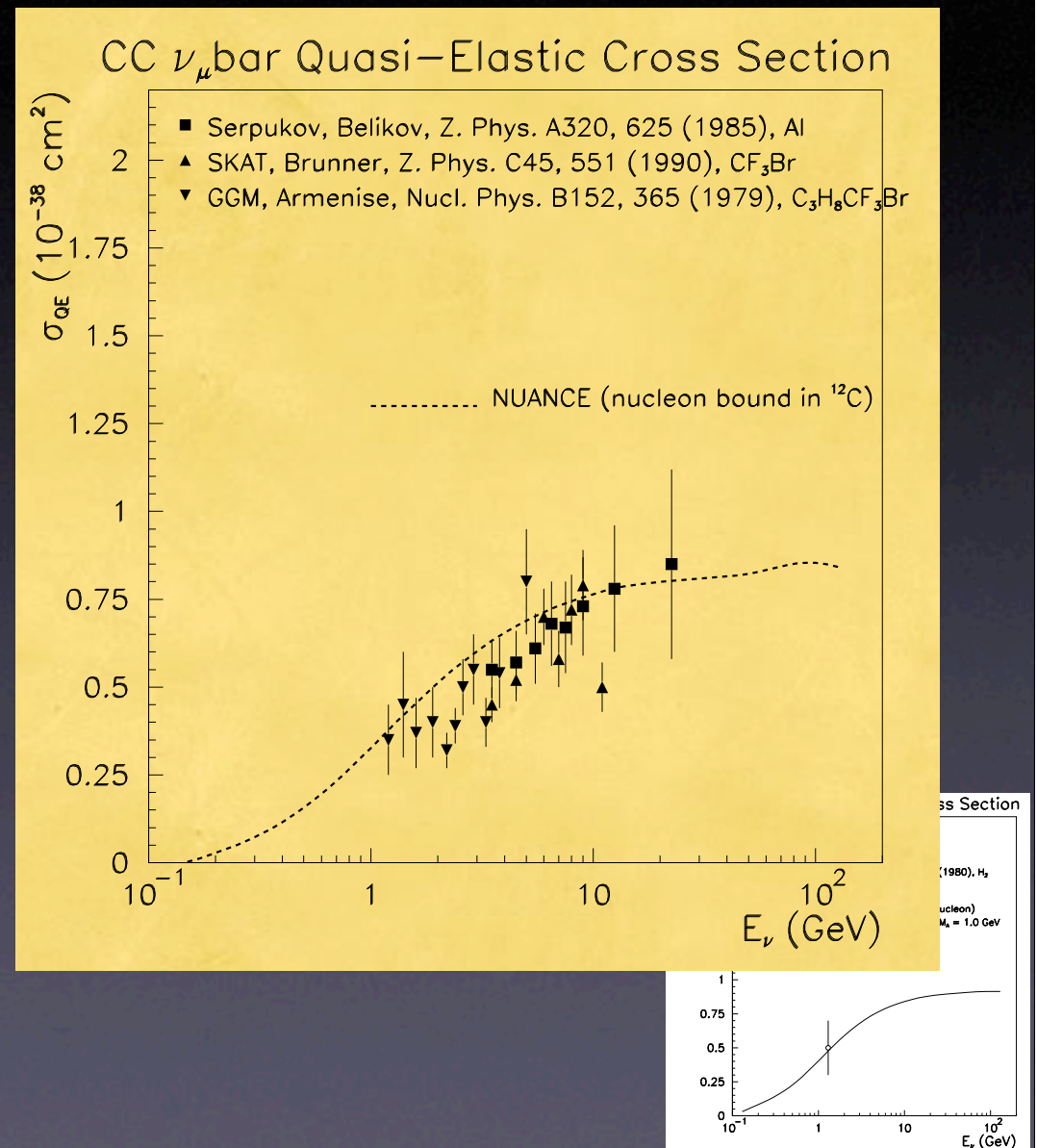
Note can only measure overall rate of WS BGs, not energy spectrum!

Status of $\bar{\nu}_\mu$ σ s

- Very few data, especially at low energy
- Not much understanding of nuclear targets
- $\bar{\nu}_\mu$ CCQE
 - ~ 1700 events
- $\bar{\nu}_\mu$ NC π^0
 - Only one (1) measurement ever.
- $\bar{\nu}_\mu$ CC π^-
 - ~ 1300 events

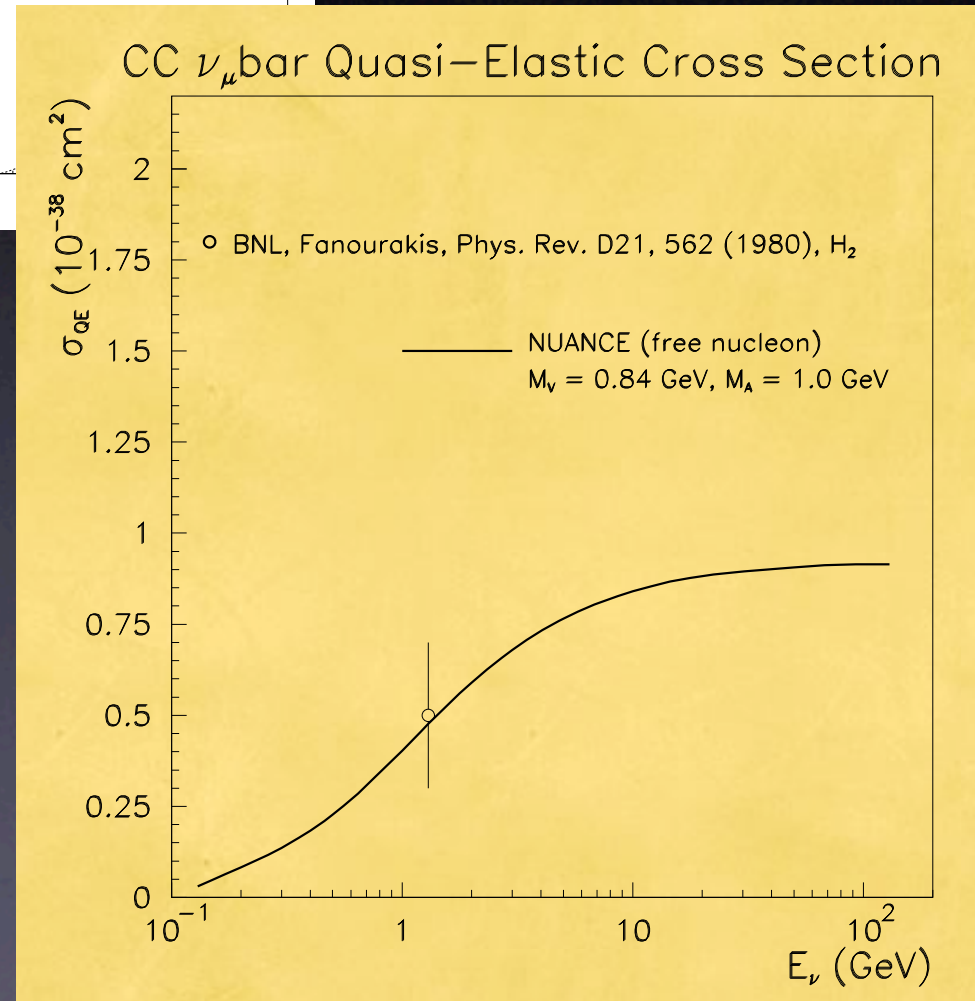
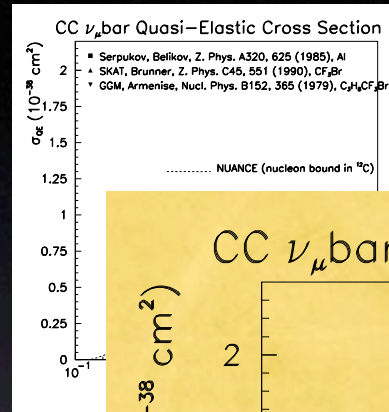
$\bar{\nu}_\mu$ CC QE Scattering

- Few $\bar{\nu}_\mu$ QE measurements
- None below 1 GeV
- MiniBooNE expects ~40,000 events before cuts for 2E20 POT



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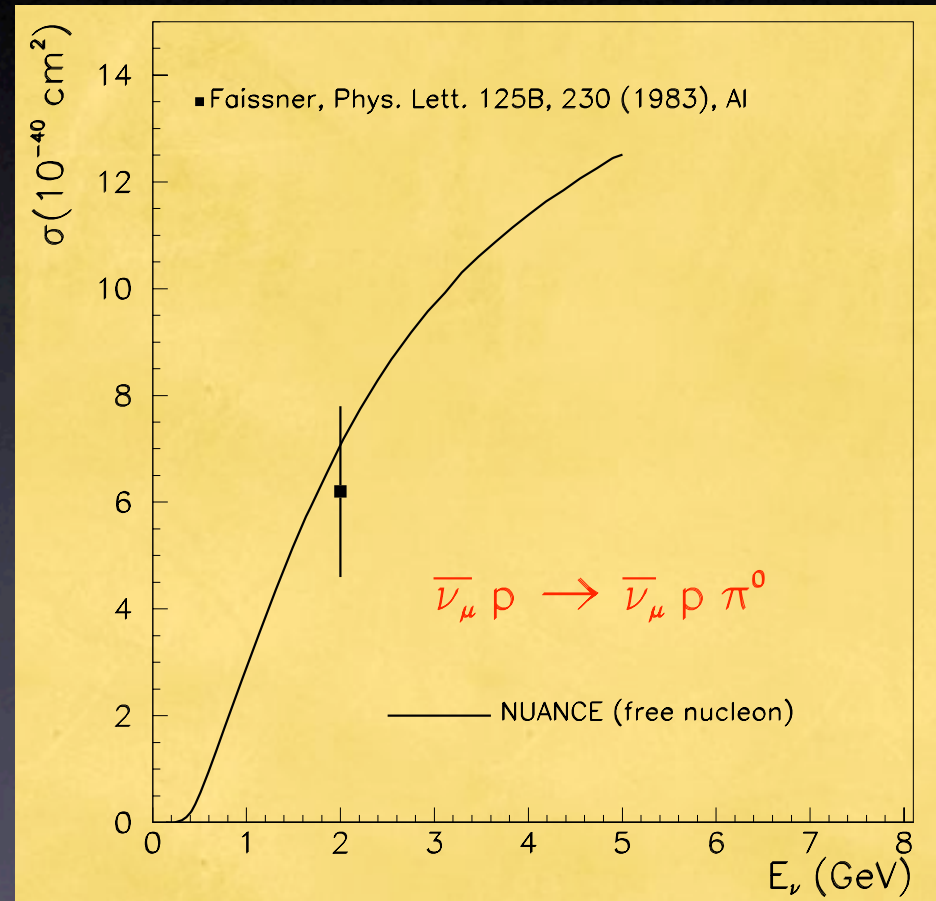


$\bar{\nu}_\mu$ CC QE Scattering

<E>	Experiment	target	date	#QE evts
2 GeV	Gargamelle	C ₃ H ₈ CF ₃ Br	1979	766
1.3 GeV	BNL	H ₂	1980	13
16 GeV	FNAL	NeH ₂	1984	405
6-7 GeV	SKAT	CF ₃ Br	1988	92
9 GeV	SKAT	CF ₃ Br	1990	159
5-7 GeV	SKAT	CF ₃ Br	1992	256
				1691

$\bar{\nu}_\mu \text{ NC } \pi^0$

- Only one measurement of $\bar{\nu}_\mu N \rightarrow \bar{\nu}_\mu N \pi^0 N$ to date¹
 - 25% uncertainty at 2 GeV
- Important for $\bar{\nu}_e$ appearance searches
- Coherent production more apparent in antineutrino scattering



¹This appeared as a footnote in Faissner et al., Phys. Lett. 125B, 230 (1983)

CC π^- Events

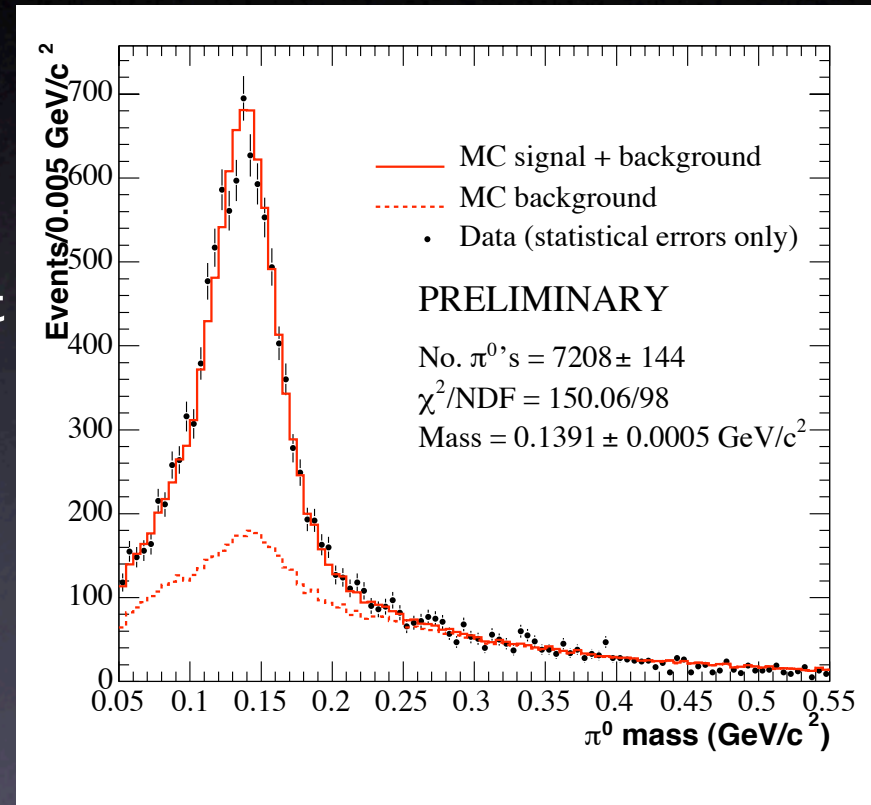
$\langle E \rangle$	Experiment	target	date	#CC π^- evts
1.5 GeV	Gargamelle	C ₃ H ₈ CF ₃ Br	1979	282
5-70 GeV	FNAL	H ₂	1980	247
5-200 GeV	BEBC	D ₂	1983	300
25 GeV	BEBC	H ₂	1986	375
7 GeV	SKAT	CF ₃ Br	1989	120
				1324

$\bar{\nu}_\mu$ CC QE Scattering

- Expect $\sim 32,000$ $\bar{\nu}_\mu$ CC QE interactions within fiducial volume for $2E20$ POT
- MiniBooNE's current CC QE event selection:
 - Tank (>100) & veto (<6) PMT hit cuts
 - Fisher discriminant cut on event topology parameters
 - Select single, μ -like ring
- Using CC QE event selection, expect $\sim 19,000$ events
 - 75% pure QE (30% of those are WS)
 - May be improved with further refinements for $\bar{\nu}_\mu$
- Using WS constraints, expect to measure $\bar{\nu}_\mu$ CC QE cross section with $\sim 20\%$ uncertainty

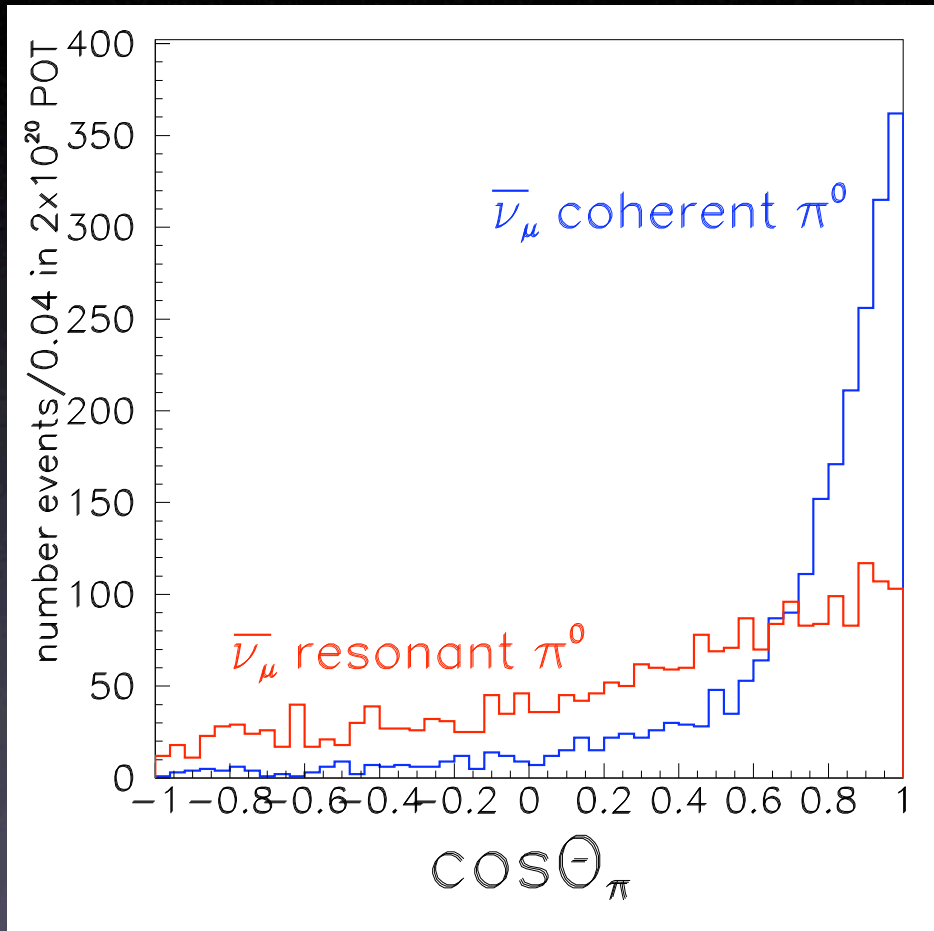
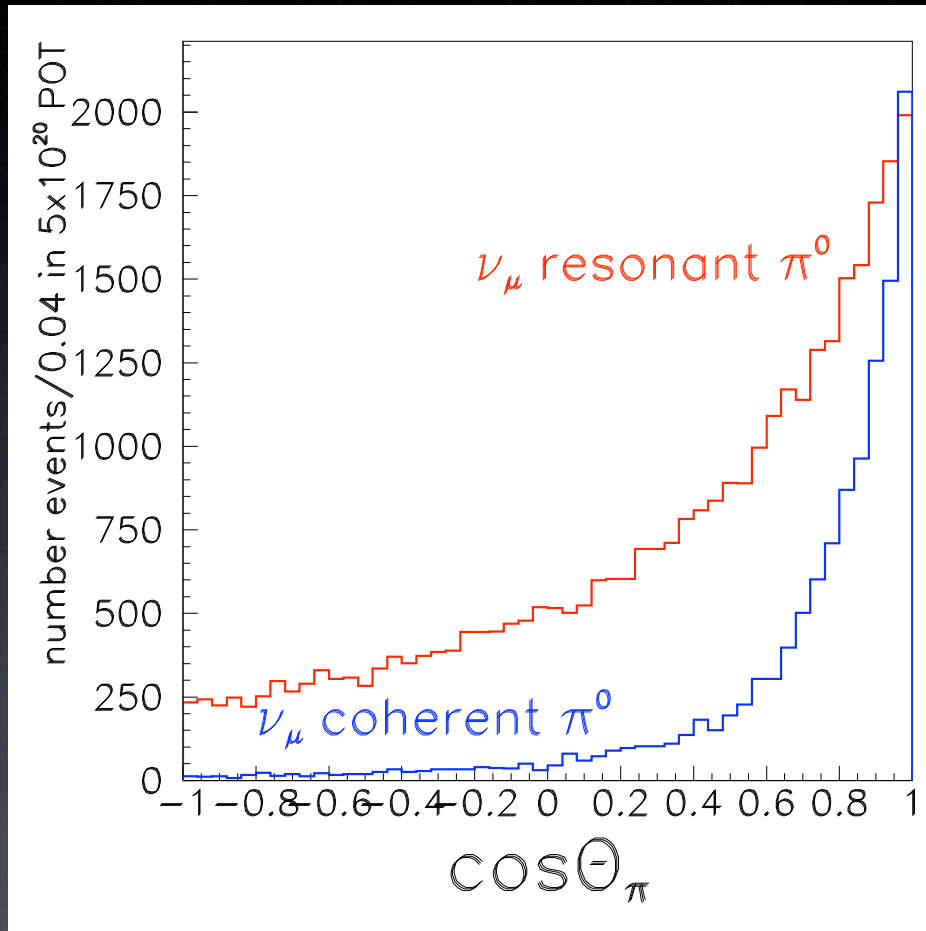
$\bar{\nu}_\mu \text{ NC } \pi^0$

- Expect $>5000 \bar{\nu}_\mu \text{ NC } \pi^0$ events within fiducial volume for 2E20 POT
- MiniBooNE's event selection requires:
 - Tank (>200) & veto (<6) PMT hit cuts
 - Two-ring reconstruction
 - $m_{\pi^0} > 50 \text{ MeV}/c^2$, $E_\gamma > 40 \text{ MeV}$
- Application of event selection should yield
 - 1650 resonant events
 - 1640 coherent events (Rein & Sehgal)
 - ~ 1000 VWS events



Reconstructed π^0 mass

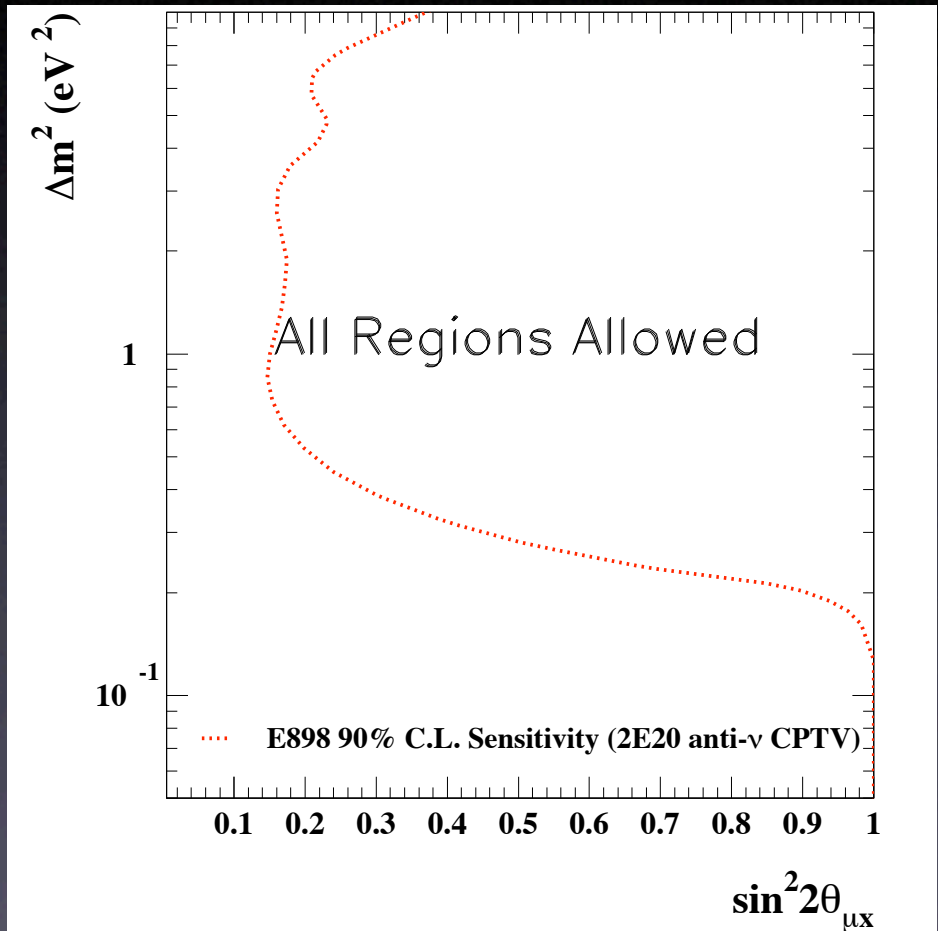
$\bar{\nu}_\mu \text{ NC } \pi^0$



- Given the K2K coherent CCI π search, antineutrino running should be very interesting! (And very obvious.)

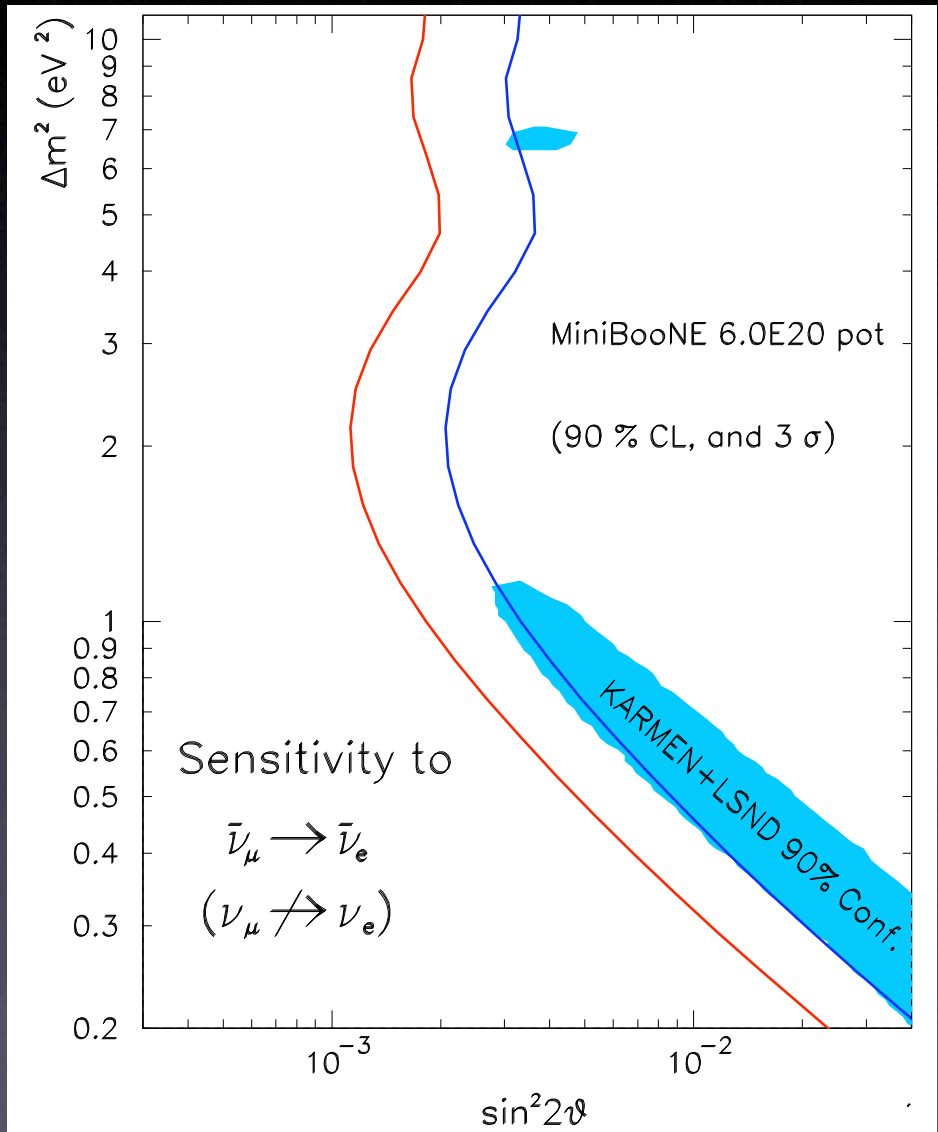
$\bar{\nu}_\mu$ Disappearance

- Oscillation appearance searches are sensitive to CPV, but not CPTV
 - Need disappearance search as well to distinguish between CPV and CPTV
- MiniBooNE can perform both searches
- Shown: CPT violating case
 - ν_μ do not oscillate, but $\bar{\nu}_\mu$ do oscillate
- Note: no existing limits on CPTV ν_μ disappearance



$\bar{\nu}_e$ Appearance

- Recall, LSND oscillations were seen in antineutrinos
 - $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
 - True confirmation can only be made with antineutrino running!
- Shown: appearance sensitivity region for antineutrino oscillations in the case of no oscillations in neutrinos
 - Compare to LSND-KARMEN joint analysis allowed region
- Statistics limited!



Conclusions

- MiniBooNE can open up the antineutrino cross section landscape with just one year of data
- We have developed several novel techniques to constraining the overall level of WS BGs
- Approved to run through end of 2006
- Might switch to antineutrino running before the FNAL accelerator shutdown
 - Shutdown to begin in Feb. '06 (± 1 month)

Conclusions

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Thanks to the organizers
for the invitation
and support!

- MiniBooNE antineutrino running:
 - “Addendum to the MiniBooNE Run Plan: MiniBooNE Physics in 2006”
 - <http://www-boone.fnal.gov/publicpages/loi.ps.gz>
- SciBar at BNB
 - “Bringing the SciBar Detector to the Booster Neutrino Beam”
 - <http://home.fnal.gov/~wascko/scibar.pdf>